CHARACTERIZATION TECHNIQUES FOR MINIATURE LOW-POWER X-RAY TUBES

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ABSTRACT

An X-ray shielded test chamber has been designed and built that includes a CCD-pinhole camera and energy-dispersive silicon PIN-diode detector for spectrum collection. The use of this chamber is an innovative approach that allows rapid imaging of the electron beam spot on the anode, as well as the spectral characterization of the tube. The beam-spot dimensions and location can be measured at several high-voltage settings to ensure stability. This setup allows monitoring spectral contamination lines, total output flux, and net target-peak intensity at the anode line. To ensure tube X-ray output stability a spot-stability test is performed. Relative standard deviations of less than 1% are typical. Leakage current must be very low since operating conditions are typically less than 10 μA of emission current. In the case of arcing tubes the measurement of leakage current is problematic, as arcing will damage the measuring equipment. By using a resistor string and measuring the voltage drop across this string, it is possible to achieve a very sensitive current measurement while protecting the meter from high-voltage transients. Finally, the filament impedance is monitored as an indicator of the tube vacuum integrity and/or the tube high internal pressure.

INTRODUCTION

Manufacture of X-ray tubes requires state-of-the-art characterization techniques. For many years photographic film has been the traditional technique for the characterization of the electron-beam spot size and location, as well as for taking X-ray images [1-4]. The use of photographic film makes this task cumbersome and lengthy since it requires the use of a dark room for film processing. The use of a charge-coupled device (CCD) camera allows imaging of the electron beam spot on the tube anode [5]. The CCD camera software also provides 3-dimensional beam-spot images, which makes the device spot-structure sensitive (Figure.1). The output spectrum of the tube can be recorded using a PIN detector This allows monitoring for spectral contamination lines, total output flux, and net target peak intensity at the anode line.

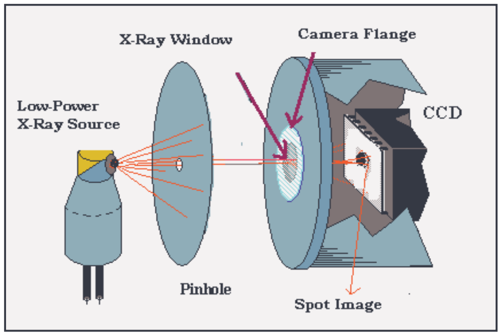

Figure 1. Pinhole-CCD camera concept for taking X-ray images

Leakage current (LC), also known as dark current, is a key tube parameter that needs to be characterized and originates by electrons flowing from the cathode to the anode just due to the presence of the high voltage applied between the two elements with the filament turned off. The potential sources of LC could be: 1) high internal pressure–"gassy" or leaky tubes, 2) internal/external contamination, and 3) microtips in the tube–field emission–especially on the cathode, the high electric field side of the tube. LC must be very low since operating conditions are typically less than 10 µA of emission current.

EXPERIMENTAL

A shielded test chamber (Figure 2) has been designed and built that includes a commercial Princeton Instruments front-side-illuminated CCD camera (which consists of an EEV 576 x 384 CCD with 22 x 22-µm pixels), a 100-µm pinhole optic, a MOXTEK PF1000 energy-dispersive silicon PIN-diode detector with a 750-µm thick crystal for the tube spectrum collection, and an oil-bath (fluorinert) tube holder. The CCD camera allows imaging of the electron beam spot on the tube anode. Due to the simplicity and quickness of this technique the beam spot dimensions and location can be measured at several high-voltage settings to ensure stability in a matter of a few minutes. The distances between the tube window and the CCD and the X-ray detector are kept at 9 cm and 35 cm, respectively.

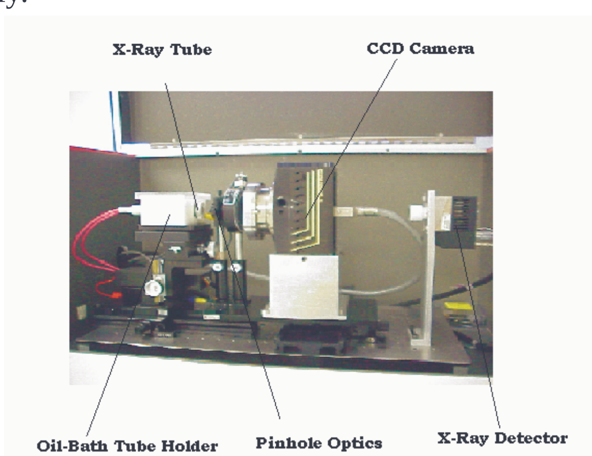

Figure 2. X-ray shielded camera

RESULTS

Figure 3 shows a typical X-ray spectrum of a bare tube with no collimator on the window and the beam spot on the side (insert). Three regions can be seen: 1) the low-energy region (below 3 keV) where the X-rays are absorbed by the air between the tube window and the X-ray detector, 2) the medium-energy region where most of the bremsstrahlung radiation and contamination peaks occur and 3) the high-energy region (above 18 keV) where the Ag-target peaks appear and in which the PIN diode detector has poor sensitivity. The contamination peaks are associated to back-scattered electrons exciting the anode metallic support, which consists mainly of Fe, Ni, and Cu. This contamination effect is enhanced by the electrons hitting the window side. This effect can be also seen as a halo around the outside diameter tube window as illustrated in the insert.

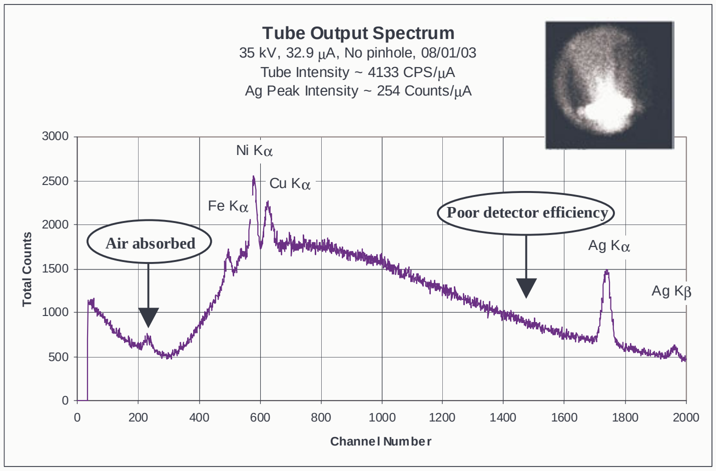

Figure 3. Typical X-ray spectrum of a tube with no collimator and near-edged beam spot (insert)

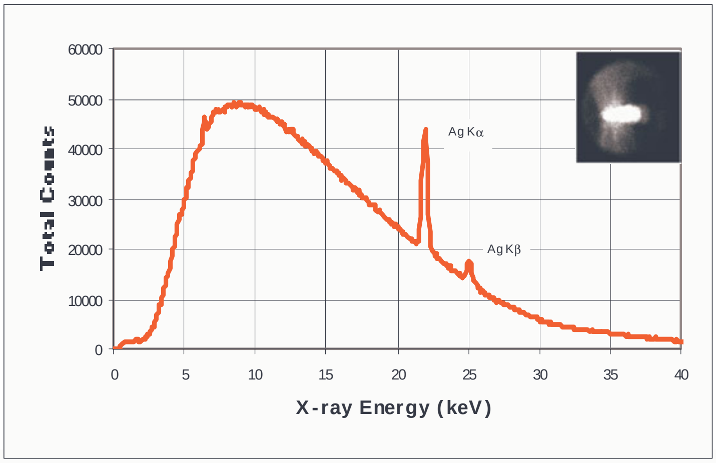

Figure 4. Typical X-ray spectrum of a tube with a collimator and near-centered beam spot (insert)

Figure 4 shows a typical X-ray spectrum of a bare tube with a collimator on the window and the beam spot nearly on the center (insert). In contrast to Figure 3, the medium-energy region shows minimal spectral contamination and the beam-spot image exhibits no halo, which is in agreement with the absence of contamination peaks in the X-ray spectrum.

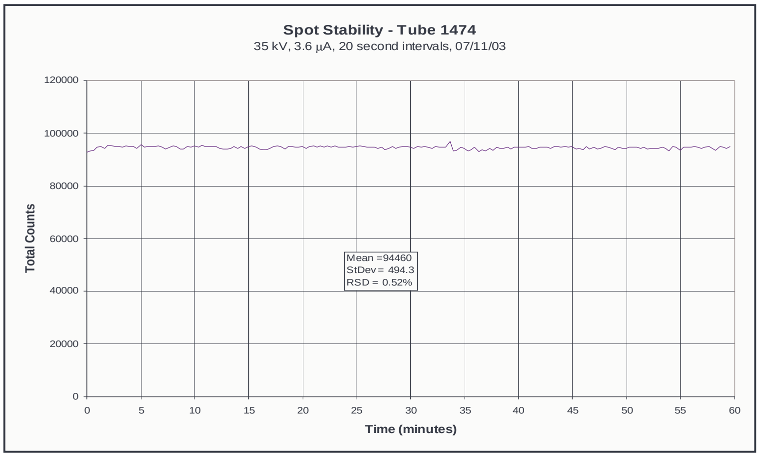

Figure 5. Typical graph of the X-ray detector total number of counts vs. time for a stable tube run at 35 KV and 3.5 µA

To ensure the tube X-ray output stability a spot-stability test is performed. Figure 5 is a typical graph of the X-ray detector total number of counts versus time for a stable tube run at 35 KV and 3.5 µA of emission current for 60 min. Data is collected at 20-second intervals. Relative standard deviations of less than 1% are typical.

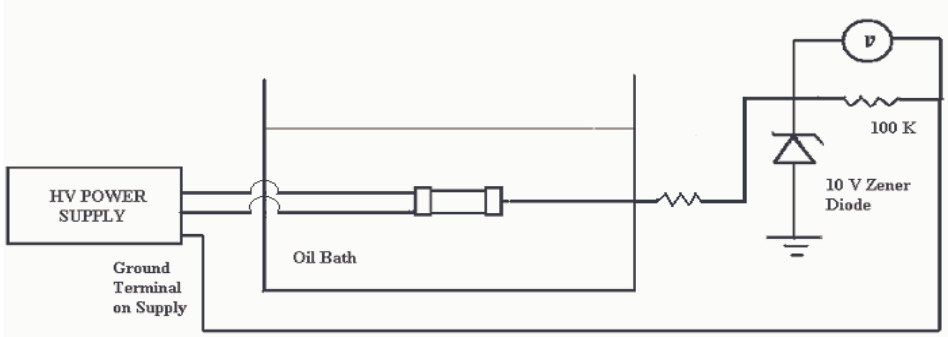

Fig. 6. Electrical circuit to measure leakage current

The measurement of leakage current is problematic, as arcing is a common event in the tubes. This will damage the measuring equipment. By using a resistor string (Figure 6) and measuring the voltage drop across a 100-KΩ resistor, it is possible to achieve a very sensitive current measurement while at the same time protecting the meter from high-voltage transients.

Figure 7 shows a typical leakage-current stability test, run at 30 KV for 120 min. Typical values are less than 0.05 µA, as indicated in Fig. 7.

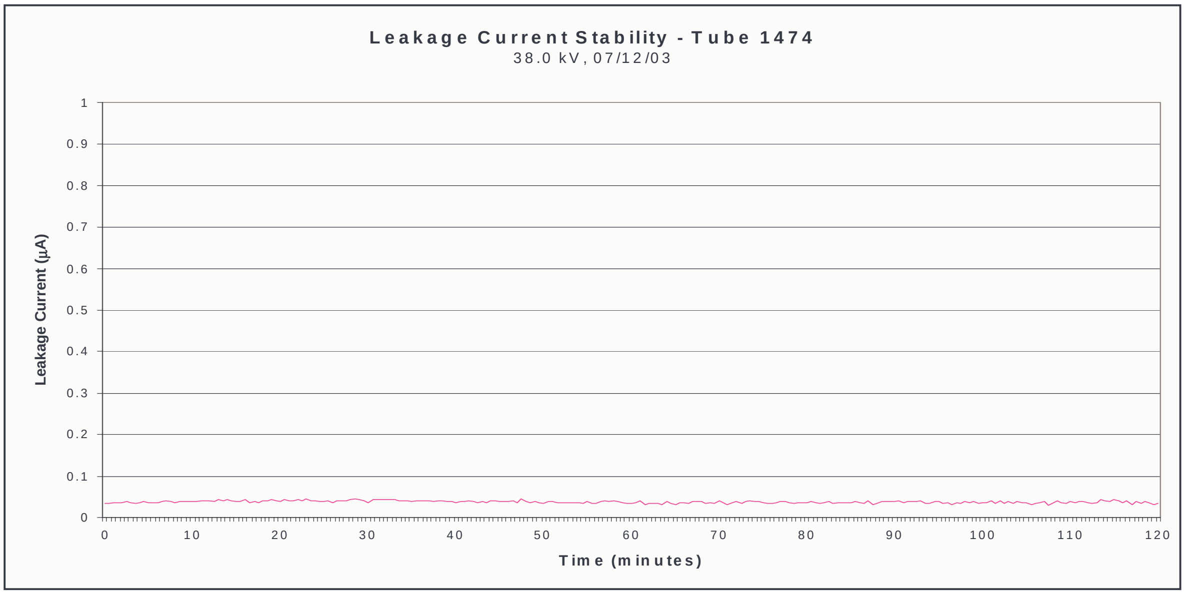

Figure 7. Typical leakage-current stability test

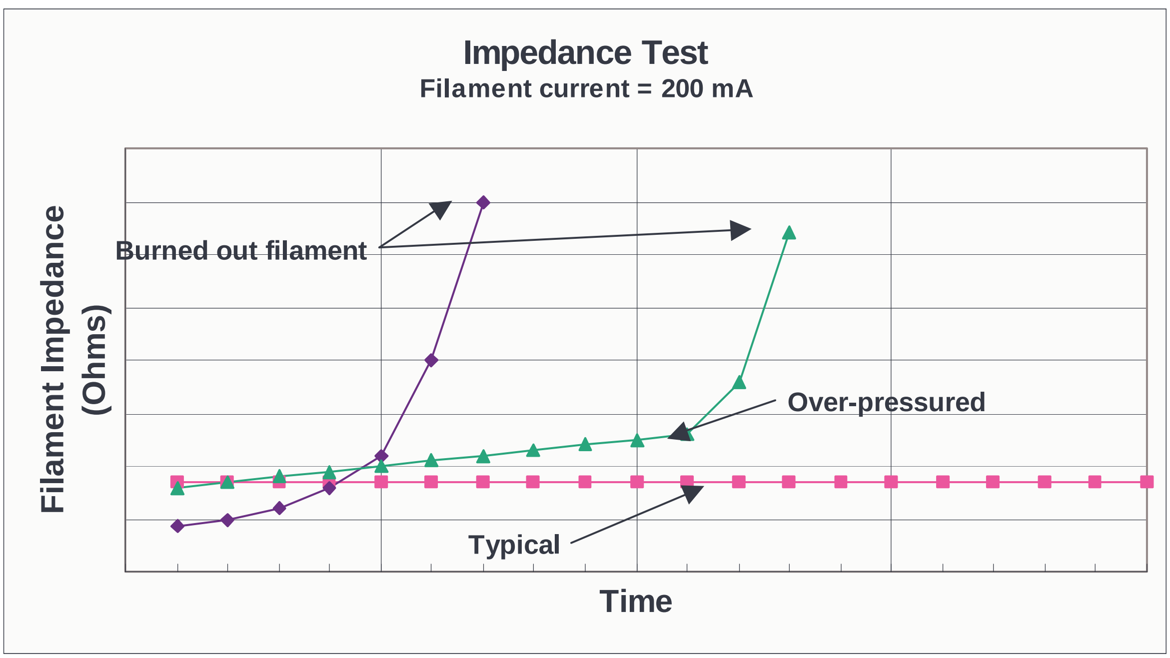

Figure 8. Three typical filament-impedance behaviors a tube filament can undergo

Finally, the filament impedance is monitored as an indicator of the tube vacuum integrity and/or the tube high internal pressure. Figure 8 exemplifies three typical filament-impedance behaviors a tube filament can undergo. 1) A fairly stable impedance value is an indication of a tube with good vacuum integrity and low internal pressure. 2) A rapid-increasing impedance within a short period of time (few minutes) is typical of a failed or anomalous tube. This behavior is associated with a leaky tube and/or high enough internal pressure that cause the filament to become oxidized and, subsequently burned out. 3) A slow-increasing impedance due to small leaks is difficult to detect over a reasonable time period. To accelerate and make any filament impedance change visible, the tubes are overpressured in air. Overpressure failed-tube filaments usually show faster impedance changes, burning out in reasonable time periods (few minutes).

SUMMARY/CONCLUSIONS

An X-ray shielded test chamber has been designed and built that includes a CCD-pinhole camera and energy-dispersive silicon PIN-diode detector. The use of this chamber is an innovative approach that allows rapid imaging of the electron beam spot on the anode, as well as the spectral characterization of the tube. The CCD digital method's accuracy, repeatability, time-savings and electronic storage/retrieval capabilities, in contrast to traditional photographic film, make it a useful quality control tool in a production environment. The CCD camera software also provides 3-dimensional beam-spot images, which make the device spot-structure sensitive, a useful feature for some applications. The output spectrum of the tube is recorded with the PIN-diode detector, allowing the monitoring of spectral contamination lines, total output flux, and net target peak intensity at the anode line. To ensure the tube X-ray output stability a spot-stability test is performed. Relative standard deviations of less than 1% are typical. Leakage-current measurements are problematic, as arcing tubes are common events. By using a resistor string and measuring the voltage drop across this string, it is possible to achieve a very sensitive current measurement while protecting the meter from high-voltage transients. Typical leakage currents are less than 0.05 μA. Finally, the filament impedance is monitored as an indicator of the tube vacuum integrity and/or the tube high internal pressure.

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